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DIURNAL CYCLES OF LAND SURFACE TEMPERATURES

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ABSTRACT

Monthly mean diurnal cycles of temperatures over land, T_S, have been analyzed. Data include a 19-year climatology of station observations of ground and air temperatures, separately for all and clear skies (T_{ga}, T_{gc}, T_{aa}, T_{ac}, respectively) over 75 sites in Russia, and a 7-year near-global climatology of satellite observations of surface temperature, T_{sat}, derived from the International Satellite Cloud Climatology Project (ISCCP) data with (280 km)^2 spatial resolution. Here, we represent diurnal cycles of all T_S in a compressed form using principal component analysis (PCA), and find that two temperature parameters describe the diurnal cycle fairly accurately. The all-sky ground temperature resembles the ISCCP derived T_{sat} most closely.

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INTRODUCTION

Our particular interest in this problem stems from working with multi-year time series of T_S from NOAA satellites, which take their observations at different local times because of specific orbital configuration (Gutman and Ignatov, 1995). A comprehensive system of monitoring T_S would be based on approximating the diurnal cycle with a function which has only a few parameters that fully characterize the thermal regime at the surface. In this study, we use geostationary satellite and station data to develop a two-parameter model of the diurnal cycle, bearing in mind its future potential synergistic use with the thermal data from NOAA polar orbiters.

Satellite Data. Global data for study of surface temperatures diurnal cycles, T_{sat}, have been generated by ISCCP by processing observations from several geostationary satellites for the period 1983-90 (Rossow and Shiffer, 1991). Top-of-the-atmosphere clear-sky radiances have been obtained at the cloud detection stage and corrected for the atmospheric effect. T_{sat} is derived by assuming the surface emissivity equal to 1. The variable "mean surface temperature for clear sky composite", available from the ISCCP Monthly Cloud Product on CD-ROM (ISCCP, 1992), is a statistical summary of the original satellite observations presented in eight 3-hour intervals, from 00 through 24 UTC, in equal-area (280 km)^2 projection. In the present study, we have analyzed the ISCCP climatological data, obtained by averaging out monthly fields for seven years (1983-90). This yields 96 monthly maps: 12 months x 8 UTC times. Only land regions, not including coasts, within ±60° latitude/longitude belt (cf. with Carlson et al., 1995) with data available for all 8 diurnal 3-hour intervals during each of 12 months were used in the analysis. This yields 1233 equal-area grids for each observation time, which amounts to 14796 (12x1233) diurnal cycles per year. Figure 1 shows spatial coverage by ISCCP data. The ISCCP T_{sat} data are advantageous in that they are representative of large spatial areas and provide a complete diurnal cycle on a near-global, uniform and internally consistent basis. At the same time, being a by-product of a cloud-oriented project, they should be additionally quality-controlled and checked.

Station Data. We have merged the ISCCP data with in-situ temperature measurements at primary stations of the USSR (Dr. P.Groisman, personal communication). The station data include standard measurements of air (T_a) and ground (T_g) temperatures, and cloudiness in eight 3-hour intervals, from 00 through 24 UTC. For the present study, we have used 19-year monthly climatologies of all-sky and clear sky-temperatures: T_{aa}, T_{ac}, T_{ga}, T_{gc}.

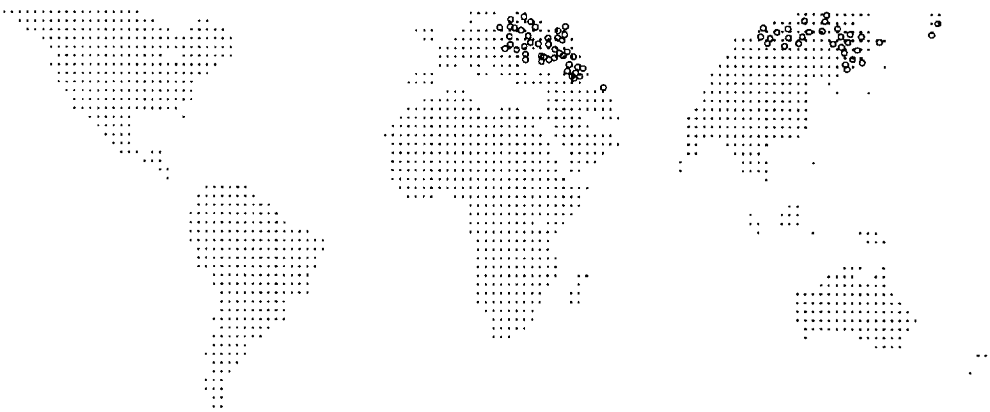

Fig.1. Coverage by ISCCP data (dots) and 75 former USSR stations (circles).

These climatologies have been aggregated from the individual daily measurements and kindly provided to us by Dr. P. Groisman. Detailed description of the data can be found in (Groisman et al., 1996).

In what follows, we consider two samples: 1) the near-global ISCCP sample which includes 14796 points (=1233 data points in space in Figure 1 x 12 months); and 2) its subsample, merged with 75 stations over the USSR (900 = 75 stations x 12 months). We refer to these two samples as the "global" and "station" samples, respectively.

PRINCIPAL COMPONENT ANALYSIS (PCA)

Two-Parameter Representation of Diurnal Cycles. The UTC was converted to local solar time (LST), and respective T_S interpolated to integer hours (cf. with Carlson et al., 1995). This results in representation of the T_S diurnal cycles by 24-dimension vectors $\mathbf{T_S}=\{T_{S1},..,T_{S24}\}$. The five mean diurnal cycles, calculated for the station sample by averaging 900 respective vectors $\mathbf{T_S}$, are shown in Figure 2, along with the global mean diurnal cycle from ISCCP data. The centered vectors, formed by subtracting mean diurnal cycles, were subjected to PCA. The covariance matrices were formed, and their eigenvectors (or empirical orthogonal functions, EOFs), $\mathbf{e}_{S,i}$, and eigenvalues, $\lambda_{S,i}$, were calculated. The first two EOFs are shown in Figure 3. Each vector is represented as $\mathbf{T_S}=\bar{\mathbf{T}}_S+\sum\alpha_{S,i}\cdot\mathbf{e}_{S,i}$. The coefficients α_i -- the loadings on vectors $\mathbf{e}_{S,i}$ -- are referred to as the principal components (PCs). Table 1 shows that all the diurnal cycles are described by two EOFs well within RMS error of <1°C.

Table 1. Root-Mean-Squared Approximation Errors (°C) of the Diurnal Cycles

	aver	EOF 1	EOFs 1&2	EOFs 1&2&3
Taa	13.4	1.1	0.4	0.3
Tga	15.6	2.1	0.7	0.5
Tac	15.2	1.6	0.8	0.6
Tgc	18.6	2.4	1.1	0.8
Tsat	14.9	2.0	0.8	0.6
Tsat (global)	12.5	3.5	1.0	0.7

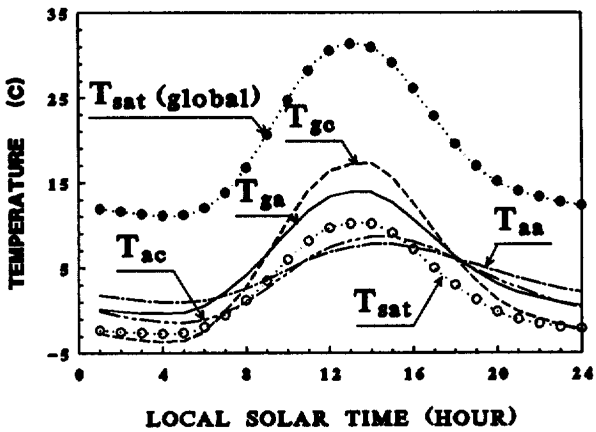

Fig.2. Average diurnal cycles in station and satellite T_S.

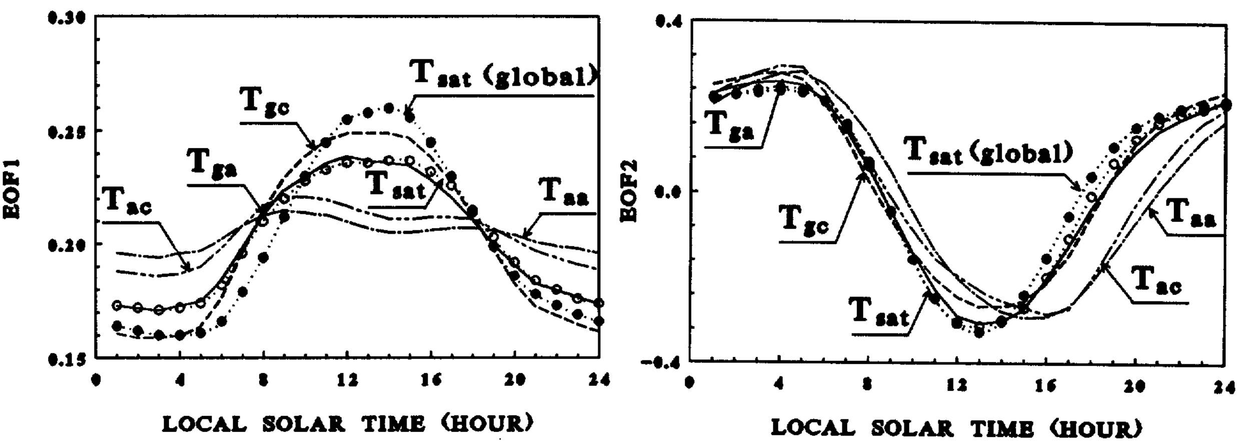

Fig.3. First two EOFs of the diurnal cycles in the station and satellite temperatures.

CONVERTING PCs TO TEMPERATURE PARAMETERS

Two Temperature Parameters Instead of the Two PCs. The diurnal cycle of T_S is closely described by the first two PCs. The more traditional variables used in meteorology to characterize the temperature are the daily mean ($\bar{T}$), minimum (T_{min}), maximum (T_{max}), and the diurnal range ($\Delta T = T_{max} - T_{min}$).

Optimization of Observation Times to Derive $\bar{T}$ and ΔT. Observations at two times, $T(h_1)$ and $T(h_2)$, allow estimating $\bar{T}$ and ΔT using linear relationships: $\bar{T} = \alpha_0 + \alpha_1 T(h_1) + \alpha_2 T(h_2)$; $\Delta T = \beta_0 + \beta_1 T(h_1) + \beta_2 T(h_2)$, where the coefficients α_i, β_i (i=0,1,2) are functions of (h_1, h_2). Optimal times ($h_{1,opt}$, $h_{2,opt}$) are defined as those which bring the RMS errors of the respective regressions to minimum. Bivariate analysis has shown that, to a good approximation, $h_{1,opt}$ corresponds to T_{max} (day-time), and $h_{2,opt}$ to T_{min} (night-time measurement). For ground and satellite temperatures, $h_{1,opt} \approx 13{:}30 \pm 0{:}30$; $h_{2,opt} \approx 4{:}00 \pm 1{:}00$ LST ($\bar{T} \approx 0.6T_{min} + 0.4T_{max}$; $\Delta T = T_{max} - T_{min}$); for air temperatures $h_{1,opt} \approx 15{:}00 \pm 1{:}00$; $h_{2,opt} \approx 4{:}00 \pm 1{:}00$ LST ($\bar{T} \approx 0.5(T_{min} + T_{max})$; $\Delta T = T_{max} - T_{min}$), respectively.

Prediction of the Full Diurnal Cycle Using $\bar{T}$ and ΔT. Once $\bar{T}$ and ΔT are known, one can reconstruct the full diurnal cycle using a linear relationship $T(h) = \gamma_0(h) + \gamma_1(h)\bar{T} + \gamma_2(h)\Delta T$ with accuracy shown in Figure 4.

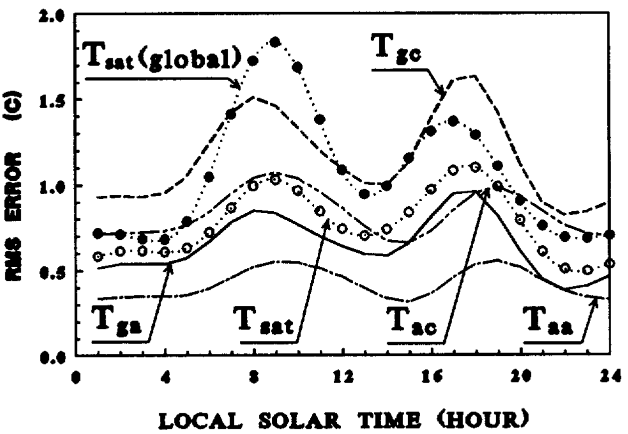

Fig.4. RMS error of estimate $T(h) = \gamma_0(h) + \gamma_1(h)\bar{T} + \gamma_2(h)\Delta T$.

Comparison of T_{sat} With Station Temperatures. Comparing average cycles and EOFs for different types of temperatures (Figs.2,3) suggests that the PCA statistics of T_{sat} resemble most closely those of T_{ga}, and to a lesser extent those of T_{gc}. The PCA statistics of air temperatures form a pattern, which differs significantly from both satellite and ground temperatures. The minimum in all average diurnal cycles is observed between 4 and 5 LST, and the maximum between 13 and 14 LST for the ground and satellite temperatures (cf. with Carlson et al., 1995), and between 14 and 15 LST for the air temperature. All the $\bar{T}_S$ have asymmetrical shapes, with diurnal ranges of air temperatures being about half as big as those for the ground and satellites. The shape of $\bar{T}_{sat}$ most closely resembles that of $\bar{T}_{ga}$, although there is a negative bias in $\bar{T}_{sat}$. This bias may be the impact

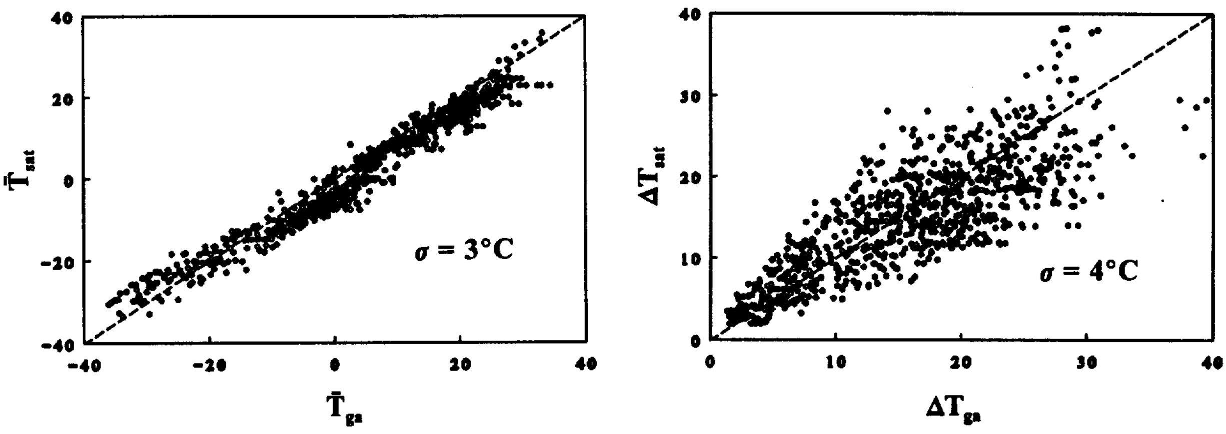

Fig.5. Regressions between satellite ($\bar{T}_{sat}$, ΔT_{sat}) and all-sky ground ($\bar{T}_{ga}$, ΔT_{ga}) temperature parameters.

of vegetation within satellite (280 km)^2 grids, or it may result from the unity-emissivity assumption. Both EOFs (Figure 3) form two well distinguishable groups: T_{sat}, T_{ga}, T_{gc} belong to one; and T_{aa}, T_{ac} to the other. A cross-correlation analysis of $\bar{T}_{sat}$ and ΔT_{sat} with all station temperatures has confirmed that both satellite parameters produce best correlation with all-sky ground temperatures (Figure 5). This conclusion must be further checked, since T_{sat} is expected to be close to air temperatures over vegetated areas. Discrepancies between satellite and station data are attributed to the difference in spatial scales and sampling and to the errors in satellite data.

CONCLUSION

The diurnal cycles in satellite and four station temperatures (air and ground, all- and clear-sky) have been investigated using principal component analysis. Although the empirical orthogonal functions (eigenvectors of the covariance matrix) differ for different temperatures, for all of them two principal components -- the loadings on the respective empirical orthogonal functions -- approximate the diurnal cycles with RMS errors of 0.4-0.8 for air, and 0.8-1.1°C for ground and satellite temperatures. Instead of principal components, one can use two temperature variables, e.g. $\bar{T}$ and ΔT, or T_{min} and T_{max}. Our study emphasizes the necessity and sufficiency of two variables to fully characterize the diurnal cycle in T_S, hence the monitoring of T_S should include these two variables. Out of four station temperatures, the statistics of all-sky ground temperatures most closely resemble those derived from satellite data.

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